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Semiconductor Processing Methods

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Dr. P Semiconductor Processing Methods

TECHNICAL FIELD

The invention pertains to semiconductor processing methods, such as, for example, methods of patterning photoresist in which an antireflective material is utilized to attenuate (for example, absorb) radiation.

BACKGROUND OF THE INVENTION

Semiconductor processing frequently involves providing a photoresist layer over a substrate. Portions of the photoresist layer are subsequently exposed to light through a masked light source. The mask contains clear and opaque features defining a pattern to be created in the photoresist layer. Regions of the photoresist layer which are exposed to light are made either soluble or insoluble in a solvent. If the exposed regions are soluble, a positive image of the mask is produced in the photoresist. The photoresist is therefore termed a positive photoresist. On the other hand, if the non-irradiated regions are dissolved by the solvent, a negative image results. Hence, the photoresist is referred to as a negative photoresist.

A difficulty that can occur when exposing photoresist to radiation is that waves of radiation can propagate through the photoresist to a layer beneath the photoresist and then be reflected back up through the photoresist to interact with other waves propagating through the photoresist. The reflected waves can constructively and/or destructively

1 interfere with other waves propagating through the photoresist to create
2 periodic variations of light intensity within the photoresist. Such
3 variations of light intensity can cause the photoresist to receive non-
4 uniform doses of energy throughout its thickness. The non-uniform dose
5 can decrease the accuracy and precision with which a masked pattern
6 is transferred to the photoresist. Also, the radiated waves reflected
7 back from a non-flat surface underlying photoresist can enter portions
8 of the photoresist that are not supposed to be exposed. Accordingly,
9 it is desired to develop methods which suppress radiation waves from
10 being reflected by layers beneath a photoresist layer.

11 A method which has been used with some success to suppress
12 reflected waves is to form an antireflective material beneath a
13 photoresist layer. Antireflective materials can, for example, comprise
14 materials which absorb radiation, and which therefore quench reflection
15 of the radiation.

16 Antireflective materials absorb various wavelengths of radiation with
17 varying effectiveness. The wavelengths absorbed, and the effectiveness
18 with which they are absorbed, vary depending on the materials utilized.
19 The number of materials available for use as antireflective materials is
20 limited. Accordingly, it is desired to develop alternative methods of
21 varying the wavelengths absorbed, and effectiveness with which the
22 wavelengths are absorbed, for antireflective materials.

1 **SUMMARY OF THE INVENTION**

2 In one aspect, the invention includes a semiconductor processing
3 method wherein an antireflective material layer is formed over a
4 substrate. At least a portion of the antireflective material layer is
5 annealed at a temperature of greater than about 400° C. A layer of
6 photoresist is formed over the annealed antireflective material layer.
7 The layer of photoresist is patterned. A portion of the antireflective
8 material layer unmasked by the patterned layer of photoresist is
9 removed.

10 In another aspect, the invention includes a semiconductor
11 processing method wherein an antireflective material layer is formed
12 over a substrate. The antireflective material layer is annealed at a
13 temperature of greater than about 400° C. A layer of photoresist is
14 formed over the annealed antireflective material layer. Portions of the
15 layer of photoresist are exposed to radiation waves, some of the
16 radiation waves are attenuated by the antireflective material as the
17 portions are exposed.

18 In yet another aspect, the invention includes a semiconductor
19 processing method wherein a solid antireflective material layer is formed
20 over a substrate. Optical properties of the antireflective material layer
21 are altered. After altering the optical properties, a layer of photoresist
22 is formed over the antireflective material layer. Portions of the layer
23 of photoresist are exposed to radiation waves. Some of the radiation
24 waves are absorbed by the antireflective material.

1 **BRIEF DESCRIPTION OF THE DRAWINGS**

2 Preferred embodiments of the invention are described below with
3 reference to the following accompanying drawings.

4 Fig. 1 is a fragmentary, diagrammatic, cross-sectional view of a
5 semiconductor wafer fragment at a preliminary processing step of a
6 method of the present invention.

7 Fig. 2 is a view of the Fig. 1 wafer fragment at a processing
8 step subsequent to that shown in Fig. 1.

9 Fig. 3 is a view of the Fig. 1 wafer fragment at a processing
10 step subsequent to that shown in Fig. 2.

11 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

12 This disclosure of the invention is submitted in furtherance of the
13 constitutional purposes of the U.S. Patent Laws "to promote the
14 progress of science and useful arts" (Article 1, Section 8).

15 A method of the present invention is described with reference to
16 Figs. 1-3. Referring to Fig. 1, a semiconductor wafer fragment 10 is
17 illustrated at a preliminary processing step. Wafer fragment 10
18 comprises a substrate 12, an overlying antireflective material layer 14,
19 and a photoresist layer 16 over the antireflective material layer 14.
20 The substrate can comprise, for example, a monocrystalline silicon wafer
21 lightly doped with a conductivity-enhancing dopant. To aid in
22 interpretation of this disclosure and the claims that follow, the term
23 "semiconductive substrate" is defined to mean any construction comprising
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1 semiconductive material, including, but not limited to, bulk
2 semiconductive materials such as a semiconductive wafer (either alone
3 or in assemblies comprising other materials thereon), and semiconductive
4 material layers (either alone or in assemblies comprising other
5 materials). The term "substrate" refers to any supporting structure,
6 including, but not limited to, the semiconductive substrates described
7 above.

8 The antireflective material layer 14 can comprise an inorganic
9 material, such as, for example, a material comprising from about 5% to
10 about 37% (by atomic concentration) oxygen, about 10% to about 35%
11 (by atomic concentration) nitrogen, from about 50% to about 65% (by
12 atomic concentration) silicon, and hydrogen. A specific example
13 inorganic material comprises about 10% (by atomic concentration)
14 nitrogen, about 25% (by atomic concentration) oxygen and about 65%
15 (by atomic concentration) silicon. Antireflective coating layer 14 can,
16 for example, consist of a single substantially homogeneous layer of the
17 above-described inorganic material.

18 As another example, antireflective coating layer 14 can comprise
19 a stack of materials, with at least one of the materials in the stack
20 being configured to attenuate radiation that passes through the
21 photoresist. The attenuation can encompass either total or partial
22 absorption of such radiation. If the attenuation encompasses only
23 partial absorption, then preferably the radiation that is not absorbed will
24 be reflected at an appropriate wavelength and phase such that it is

1 cancelled by other radiation passing through the stack. In an exemplary
2 configuration of an antireflective layer comprising a stack of materials,
3 the layer comprises a material comprising from about 5% to about 37%
4 (by atomic concentration) oxygen, about 10% to about 35% (by atomic
5 concentration) nitrogen, from about 50% to about 65% (by atomic
6 concentration) silicon, and hydrogen at the bottom of the stack. The
7 remainder of the stack comprises one or more layers that are fully or
8 partially transmissive of the radiation. Such layers can comprise, for
9 example, silicon dioxide.

10 Photoresist layer 16 can comprise either a negative photoresist or
11 a positive photoresist.

12 In accordance with the present invention, antireflective material
13 layer 14 is applied over substrate 12 and at least a portion of layer 14
14 is annealed at a temperature greater than about 400° C (preferably
15 greater than 400° C) prior to formation of photoresist layer 16. If the
16 antireflective material includes a portion comprising the above-discussed
17 inorganic materials comprising nitrogen, oxygen, hydrogen and silicon,
18 such portion can be applied by chemical vapor deposition at a
19 temperature of from about 250° C to about 400°. The portion is then
20 preferably annealed at a temperature of from about 800°C to about
21 1050°C, more preferably from about 800°C to about 900°C, and most
22 preferably about 850°C. During the anneal, the antireflective material
23 layer 14 is preferably exposed to a nitrogen-containing atmosphere, such
24

1 as an atmosphere comprising N₂ and Ar. The atmosphere can, for
2 example, consist essentially of N₂.

3 An anneal of an antireflective material layer at a temperature of
4 greater than about 400° C has been found to alter optical properties
5 of the antireflective material layer to make the antireflective material
6 layer more absorptive to radiation. Such anneal is particularly beneficial
7 for a portion of an antireflective material layer comprising oxygen,
8 nitrogen, silicon, and hydrogen. Specifically, the anneal has been found
9 to influence a refractive index coefficient (n) of the antireflective
10 material layer and an extinction coefficient (energy absorption coefficient)
11 (k) of the antireflective material layer. For instance, it has been found
12 that an anneal at greater than about 400° C of a hydrogenated material
13 comprising about 10% (by atomic concentration) nitrogen, about 25% (by
14 atomic concentration) oxygen and about 65% (by atomic concentration)
15 silicon will alter the "n" and "k" of the material exposed to 248
16 nanometer wavelength light from 2.12 and 1.19, respectively, to 1.89
17 and 1.41, respectively. Also, the anneal will alter the "n" and "k" of
18 such material when exposed to 365 nanometer wavelength light from
19 2.67 and 0.59, respectively, to 2.89 and 1.11, respectively.

20 After the anneal of at least a portion of antireflective material
21 layer 14, photoresist layer 16 is formed over antireflective layer 14.
22 Photoresist layer 16 can be formed by conventional methods. An
23 example method includes spinning a photoresist liquid over layer 14 and
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1 subsequently volatilizing solids from the layer to form a solid photoresist
2 layer 16.

3 Referring to Fig. 2, photoresist layer 16 is patterned by exposing
4 the layer to a patterned beam of radiation. Such patterning can
5 comprise conventional methods such as the negative photoresist
6 processing or positive photoresist processing described in the
7 "Background" section of this disclosure. Portions of photoresist layer 16
8 that are exposed to the radiation will behave differently in a solvent
9 than will portions unexposed to radiation. Either the portion exposed
10 to radiation or the portion unexposed to radiation is removed from over
11 substrate 12 to leave the other of the portions exposed to radiation or
12 unexposed to radiation remaining over substrate 12. Whether it is the
13 portion that is exposed to radiation that is removed or the portion that
14 is unexposed to radiation that is removed will depend on whether
15 photoresist layer 16 comprises a negative or positive photoresist. The
16 removal of a portion of photoresist layer 16 forms an opening 18
17 through photoresist layer 16. After formation of opening 18, photoresist
18 layer 16 becomes a patterned mask. A portion of antireflective
19 material layer 14 is covered by the patterned mask 16, and a portion
20 is exposed through opening 18.

21 During the exposure of photoresist layer 16 to radiation, some of
22 the radiation penetrates through layer 16 and into antireflective material
23 layer 14. Antireflective material layer 14 attenuates, and preferably
24 absorbs such penetrating radiation waves.

1 Referring to Fig. 3, opening 18 is extended through antireflective
2 material layer 14 and into substrate 12. Opening 18 can be extended
3 by conventional methods, such as, for example, a dry plasma etch or
4 a wet etch.

5 In the shown embodiment, photoresist layer 16 is against
6 antireflective material layer 14. It is to be understood that in other
7 embodiments of the invention, which are not shown, intervening layers
8 can be formed between photoresist layer 16 and antireflective material
9 layer 14. If such intervening layers are at least partially transparent to
10 the radiation utilized to pattern photoresist layer 16, the radiation will
11 penetrate to antireflective material layer 14 and be absorbed by material
12 layer 14 during exposure of photoresist layer 16 to the radiation. It
13 is also to be understood that if such intervening layers are present, a
14 pattern of layer 16 could be transferred to the intervening layers
15 without extending the pattern to layer 14. Thus, the invention
16 encompasses embodiments in which antireflective material layer 14 is not
17 etched.

18 In compliance with the statute, the invention has been described
19 in language more or less specific as to structural and methodical
20 features. It is to be understood, however, that the invention is not
21 limited to the specific features shown and described, since the means
22 ~~herein disclosed comprise~~ preferred forms of putting the invention into
23 effect. The invention is, therefore, claimed in any of its forms or
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modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.

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